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Description

METHOD AND ARRANGEMENT FOR AN INDEXING TABLE FOR MAKING SPRAY-FORMED HIGH COMPLEXITY ARTICLES

BACKGROUND OF INVENTION

[0001] 1. Field of the Invention

[0002] In at least one aspect, the present invention relates generally to a method of making spray-formed articles and, more specifically, to a method of making a complex spray-formed article using an indexing table.

[0003] 2. Background Art

[0004] Metal spraying processes are used in a number of industrial applications. Such metal spraying processes include arc spraying, plasma spraying, and flame spraying. Each of these processes is similar in that a raw material is melted and then propelled towards a work-piece at high velocity to form a coating.

[0005] In the arc spraying process, one or more metallic wires are melted by an electric arc, atomized by a compressed gas, and propelled towards a substrate. Similarly, in the flame spray process, a metallic wire or other raw material is melted by a flame and then atomized by a stream of compressed air that propels the atomized particles towards a substrate. Finally, the plasma spray process utilizes a plasma created by an electric arc burning within a plasma gun to melt either powder or consumable wires. The melted materials are atomized by a high speed gas stream and then directed to a surface which is subsequently coated. Typically, the work-piece remains cool because the plasma is localized at the gun. Plasma spray processes have been used in the automotive industry to coat the interior of engine cylinder bores. In such applications, the plasma gun will be translated and rotated through the cylinder bore.

[0006] A particularly important application of arc spraying is the spray-form process. This has been necessitated by the increasing importance of the need to rapidly produce prototype and production tooling in the automotive industry. Most important is prototype and production tooling used in stamping, die casting and molding. Currently, small

sets of prototype tooling can take from six to eight weeks to fabricate, while large production tools can take two to three months to produce. The spray-form process is capable of producing tooling in less than one month at a cost that is equal or lower than conventional methods.

[0007] In the spray-forming process, hot molten metal is sprayed onto a ceramic pattern (i.e., ceramic mold) to form a desired tool. The ceramic pattern is essentially the reverse of the desired tool to be produced. A ceramic slurry is poured onto a master model and solidified to form the ceramic pattern. Typically, the master model is produced using a free form fabrication technique. When solidification is complete, the resulting ceramic pattern is put through a series of heat cycles and becomes the receptor onto which metal is sprayed to form a deposit in the shape of the desired tool. The spray-forming process requires that such a ceramic pattern be made from a material that has excellent dimensional accuracy, superior surface finish, excellent heat transfer and low thermal expansion. A suitable ceramic material is aluminum oxide.

[0008] The spray-forming process results in a tool with a fine microstructure that has strength, toughness and ductility comparable to tools produced from typical casting meth-

ods. Residual stresses are controlled in the spray-formed article by regulation of the metal deposition temperature. Such temperature control allows for good geometric accuracy.

[0009] One typical spray-forming process comprises wire-arc thermal spraying. In a common type of wire-arc spraying, electric current is carried by two electrically conductive, consumable wires with an electric arc forming between the wire tips. A high-velocity gas jet blowing from behind the consumable wire tips strips away the molten metal, which continuously forms as the wires are melted by the electric arc. The high-velocity gas jet breaks up or atomizes the molten metal into finer particles to create a distribution of molten metal droplets. The atomizing gas then accelerates the droplets away from the wire tips towards the ceramic pattern where the molten metal droplets impact the ceramic pattern to incrementally form a deposit in the shape of the desired article.

[0010] The desired article is then removed from the ceramic pattern. The removal is typically accomplished by cutting off the perimeter of the metal deposit with a high-pressure water jet, chiseling off the majority of the ceramic pattern and then using a glass bead blaster to remove the residual

ceramic from the surface of the desired article. In the case of a tool, the completed tool is backed with a support material and then mounted and used to produce parts in conventional stamping, die casting, molding, or other tool-usable processes.

[0011] Although the above process for making a spray-formed article has worked well, complex spray-formed articles often require a prohibitively large number of spray guns to uniformly coat the intricate surfaces in such articles. This increased number of spray guns adds to equipment cost and complexity. Accordingly, there exists a need to form a spray-formed article with as few spray guns as possible.

SUMMARY OF INVENTION

[0012] The present invention overcomes the problems encountered in the prior art by providing in one embodiment an improved apparatus for forming a spray-formed article. The apparatus of the present invention forms the article by coating a mold that is the inverse of the article with a metal spray. The apparatus of this embodiment includes an indexing table for emplacement of the mold and a thermal spray gun for forming an atomized metal spray. The indexing table is rotatable in discrete increments be-

tween 0 and 360 degrees.

[0013] In another embodiment of the present invention, a method of making a spray-formed article using the spray-form apparatus of the present invention is provided. The method of this embodiment comprises:

[0014] a) providing a mold that is the inverse of the article, the mold having an exposed surface to be coated by a metallic spray;

[0015] b) placing the mold on an indexing table that is rotatable in increments between 0 and 360 degrees;

[0016] c) directing the metallic spray onto a first portion of the mold;

[0017] d) rotating the mold by a discrete angular increment; and

[0018] e) directing the metallic spray onto an adjacent portion of the ceramic mold (typically adjacent spray patterns will overlap);

[0019] f) repeating steps d) and e) until a metal-coated mold is formed wherein a substantial portion of the surface of the mold has been coated with the metal spray and the metal-coated mold comprises a metal layer over the mold.

[0020] In a variation of the invention, the mold and the metal spray are translated linearly relative to each other. For example, the mold is translated linearly along at least one

linear axis during step e for a discrete time period. Advantageously, coordination of step d and the translation of the mold allows for larger molds to be coated.

Brief Description of Drawings

[0021] The invention will now be described in greater detail in the following way of example only and with reference to the attached drawings, in which:

[0022] Figure 1a is a top view schematic of the spray-form apparatus of the present invention; and

[0023] Figure 1b is a side view schematic of the spray-form apparatus of the present invention.

Detailed Description

[0024] Reference will now be made in detail to presently preferred compositions or embodiments and methods of the invention, which constitute the best modes of practicing the invention presently known to the inventors.

[0025] With reference to Figures 1a and 1b, a schematic of the apparatus for forming a spray-formed article is provided. Spray-form apparatus 2 includes indexing table 4 upon which mold 6 is placed. Mold 6 is the inverse of the spray-formed article to be formed. In a variation, mold 6 may correspond to the positive of an article, in which

case, the metal part is not removed from the mold. Typically, mold 6 is made of a ceramic material and formed by pouring a ceramic slurry onto a master model that is solidified to form a ceramic pattern (i.e., the mold). Preferably, indexing table 4 is a rotatable table that is capable of being rotated in discrete increments in direction 8. Moreover, table 4 is translatable along direction 9, direction 10 and direction 11. Preferably direction 9, direction 10 and direction 11 are perpendicular to each other. Finally, table 4 may be tipped at an angle relative to the normal to the ground. Spray-form apparatus 2 further includes spray station 12 with thermal spray guns 14, 16, 18 mounted on spray gun holder 20. If needed, additional spray stations are added to the apparatus of the present invention. Preferably, the apparatus of the present invention includes from 1 to 5 spray stations. More preferably, the apparatus of the present invention includes 1 to 3 spray stations, and most preferably two spray stations. Furthermore, each spray station can hold one or more spray guns only limited by the space that each such spray gun occupies. Preferably, each spray station will have three spray guns. During operation, consumable metal wires 22, 24 are fed into spray guns 14, 16, 18 where

they are melted by an electric arc. High velocity gas is also fed into spray guns 14, 16, 18 through manifold 26 causing the melted metal to form metal spray 28 that is directed toward mold 6 which is subsequently coated with a metal coating. Although a single spray gun may melt any number of consumable wires, preferably two consumable wires are melted with the electric arc.

[0026] Spray gun holder 20 is mounted on robot 30 by attachment to first robot arm 32. Robot 30 also includes second robot arm 34. Robot 30 is capable of moving both robot arm 32 and robot arm 34. Furthermore, robot 30 may also be mounted on a translation table (not shown) and moved along directions 9,10, 11. Typically, robot 30 is programmed to move these components in a desired pattern such that mold 6 is spray coated in accordance with the method of the present invention as set forth below. Preferably, robot 30 may be any robot capable of positioning spray guns 14, 16,18. Preferably, maximum positioning flexibility of the spray guns is achieved with a six-axis robot. Suitable six-axis robots are the IRB 4400 line of robots commercially available from ABB Automation. Robot 30 is in communication with indexing table driver 36 by cable 37 that causes indexing table 4 to rotate.

Robot 30 is programmed to rotate indexing table 4 at the appropriate angle and appropriate times during spray-forming. Spray-form apparatus 2 also includes computer controller 38 that controls the operating parameters of the spray guns. Such operating parameters include, but are not limited to, the voltage and firing of the electric arc that melts the consumable wires, the rate at which the consumable wires are feed to the spray guns, and the flow of air that atomizes the melted metal. Alternatively, computer controller 38 may be used to control indexing table driver 36. Furthermore, computer controller 38 is optionally in communication with robot 30 through cable 40in order to monitor or adjust the operation of robot 30.

[0027] Typically, during operation, indexing table 4 is rotated by a series of increments that total at least 180 degrees. A rotation of the mold by 180 degrees allows the entire surface of the mold to be exposed to the mold guns. However, the total rotation may also be less than 180 degrees because of the ability of robot 30 to independently move around mold 6. Furthermore, rotation of the indexing table may be repeated until a desired thickness is achieved, i.e., the mold may be rotated by one or more complete rotation for a total rotation of over 360 degrees. Prefer-

ably, indexing table 4 is rotated in increments of from about 10 to about 180 degrees. More preferably, indexing table is rotated in increments from about 30 to about 180 degrees, and most preferably in an increment of about 90 degrees.

[0028] In another embodiment of the present invention, a method of making a spray-formed article using the spray-form apparatus of the present invention is provided. The method of this embodiment comprises:

[0029] a) providing a mold that is the inverse of the article, the mold having an exposed surface to be coated by a metallic spray;

[0030] b) placing the mold on an indexing table that is rotatable in increments between 0 and 360 degrees;

[0031] c) directing the metallic spray onto a first portion of the mold;

[0032] d) rotating the mold by a discrete angular increment; and

[0033] e) directing the metallic spray onto an adjacent portion of the ceramic mold;

[0034] f) repeating steps d) and e) until a metal-coated mold is formed wherein a substantial portion of the surface of the mold has been coated with the metal spray and the metal-coated mold comprises a metal layer over the mold. Typi-

cally, the metal spray is a hot metal spray. Each rotation of the mold exposes a portion of the mold adjacent to that portion which has just been coated. This newly exposed adjacent portion is then coated by the metal spray. Furthermore, it is understood that these adjacent portions will overlap to some extent. The method of this embodiment further comprises:

[0035] g) allowing the metal-coated mold to cool; and

[0036] h) separating the metal layer and the mold to provide the article.

[0037] Typically, the mold is rotated a total of at least 180 degrees. A rotation of the mold by 180 degrees allows the entire surface of the mold to be exposed to the mold guns. Furthermore, the mold may be rotated by one or more complete revolutions for a total rotation that is greater than 360 degrees. In accordance with the method of the present invention, the mold is preferably rotated in increments of from about 10 to about 180 degrees. More preferably, the mold is rotated in increments from about 30 to about 180 degrees, and most preferably the mold is rotated in an increment of about 90 degrees.

[0038] In a particularly preferred variation of this embodiment, the mold is translated linearly along at least one linear

axis during step e for a discrete time period. Most generally during step e the mold is translated along a first linear axis for a first time period; and then translated along a second linear axis for a second time period, and then finally translated along a third linear axis for a third time period. In this instance, each of the first, second, and third axes are different. More preferably, the mold is translated linearly along a first linear axis during step e for a first time period and then translated linearly along a second linear axis during step e for a second time period. In the variation, the second linear axis is different than the first linear axis. Typically, the first linear axis is essentially perpendicular to the second linear axis. The present variation allows for the maximum sized part to be coated by a given coating apparatus. Often the coating apparatus will be situated in a confined space possibly making translation of the mold in all directions impossible. Accordingly, coordination of step d and the translation of the mold allows for larger molds to be coated. For example, the mold is characterized by a maximum linear dimension. Accordingly, the discrete angular increment of step d may be selected so that the mold is translated completely along this maximum linear dimension taking account of potential

spatialrestrictions.

[0039] According to the method of the present invention, the metal spray is formed by melting one or more consumable wires with an electric arc to form molten metal and atomizing the molten metal with a high velocity gas jet. Although a single spray nozzle may melt any number of consumable wires, preferably two consumable wires are melted with the electric arc. The method of the present invention is further characterized such that the metal spray may either be stopped or not stopped during each rotation of the mold. Typically, the metal spray is not stopped during each rotation of the mold. When spraying is not stopped during rotation, the angular velocity is sufficiently high that less than about 10% of the coating formed by the metal spray-forms during rotation.

[0040] While embodiments of the invention have been illustrated and described, it is not intended that these embodiments illustrate and describe all possible forms of the invention. Rather, the words used in the specification are words of description rather than limitation, and it is understood that various changes may be made without departing from the spirit and scope of the invention.